



Biology on the Move

Chairs

Robert Full UC Berkeley

Alan Rudolph DARPA

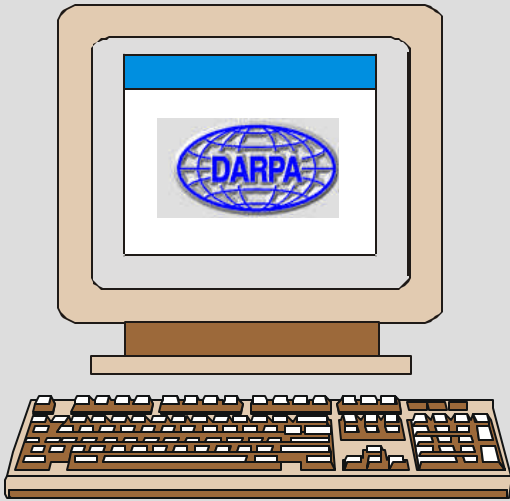
1. What are critical technical barriers, enablers and opportunities for opening the vista of technological applications?
2. What are the potential technological advancements over the temporal horizon (3-15 years)
3. What are the Defense relevant implications of success?

Vision - Next Revolution?

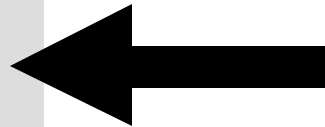


Future

Internet

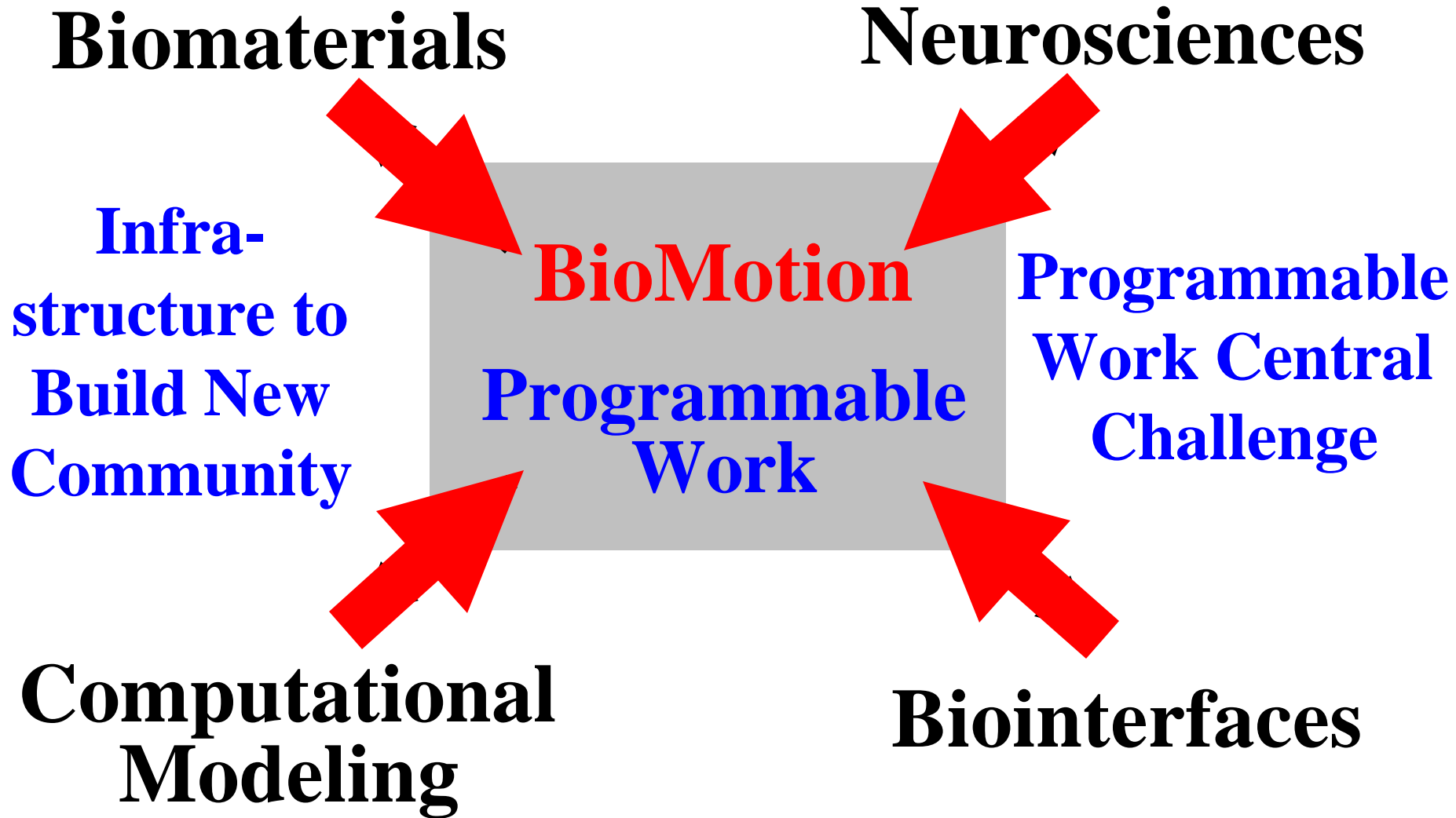


**Worldwide
Information
Transfer**



Eyes and Ears

Age of Integration



Challenge



Even if we had exceptional

Batteries

Actuators

Sensors

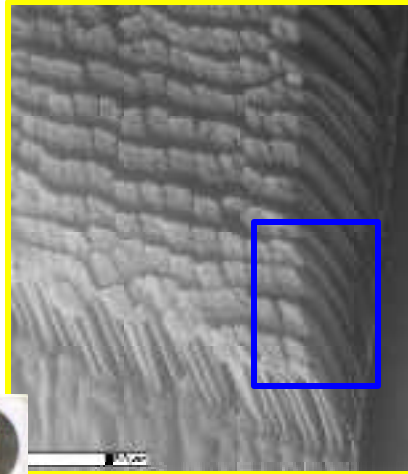
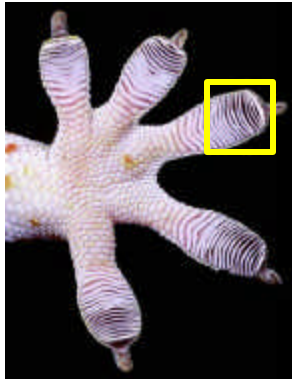
**Could not make a
mobile platform with
Biological Performance**

How is energy managed?

What is being controlled?

System integration?

Adhesion for Climbing



**2 million
hairs**

**Study
animal
running
up wall.**



**2 billion ends
per hair**

**How do
hairs
stick?**

Adhesive Force of Single Hair



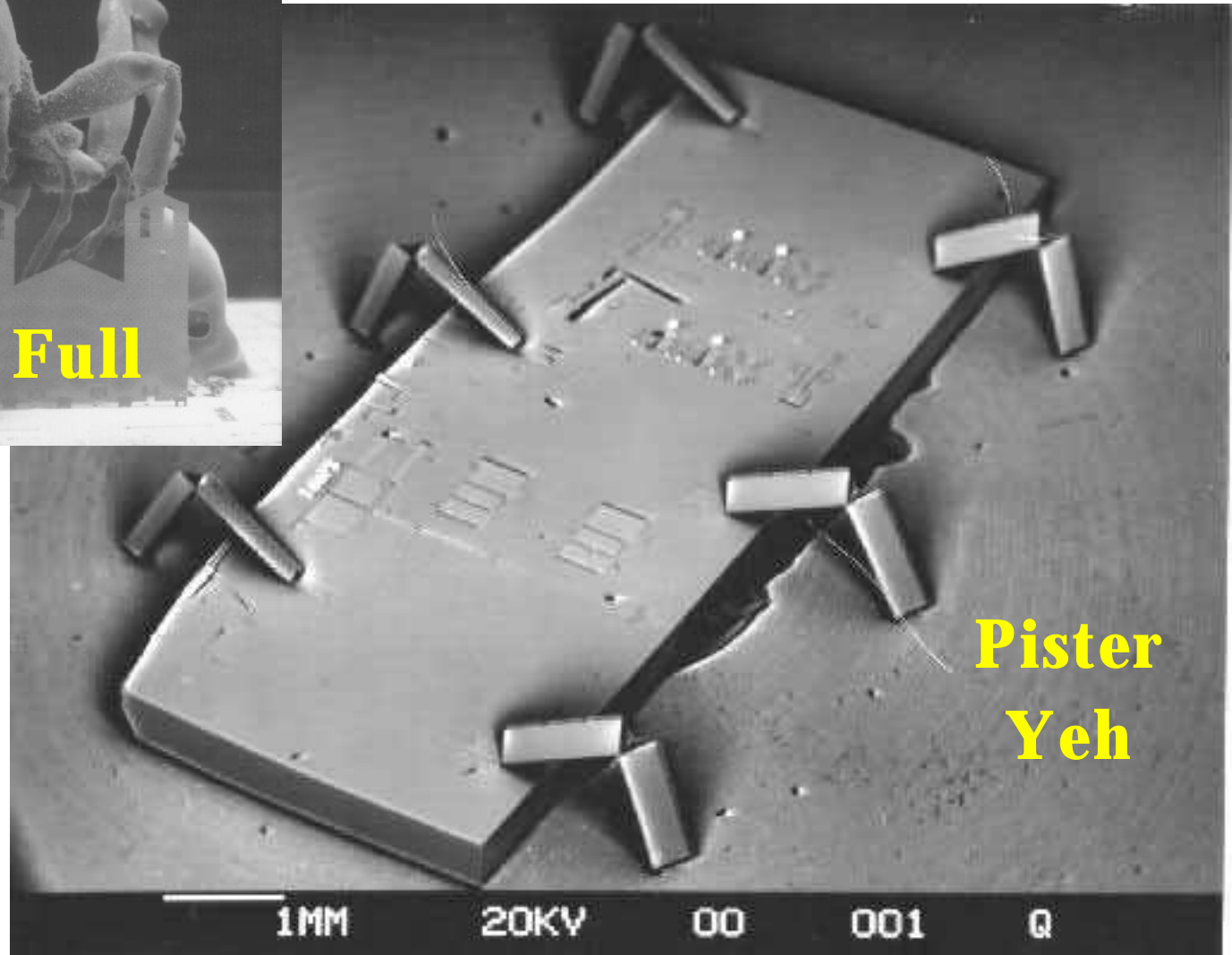
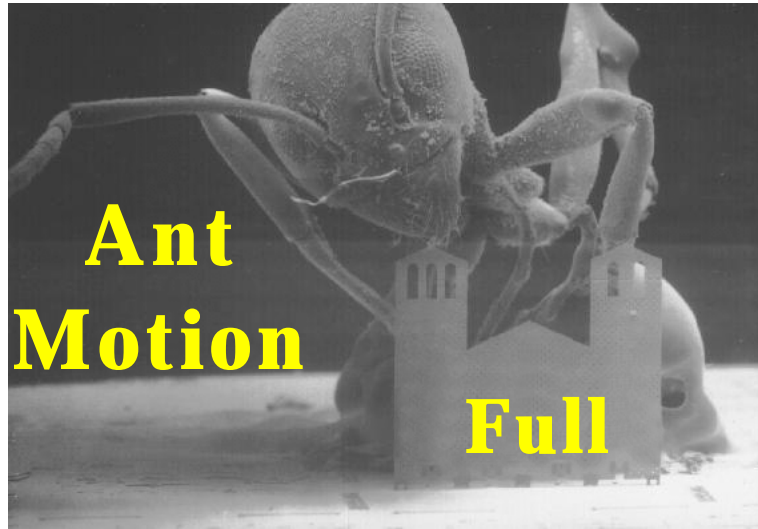
**Could NOT
determine function
of adhesive hair
without knowledge
of use during
locomotion**

Integrated System

QuickTime™ and a
Video decompressor
are needed to see this picture.

**Hairs require
preloading and
peeling. Use
intermolecular forces**

Walking Silicon



*UC
Berkeley*

Key Enablers



- 1. Design concept**
- 2. Energy management**
- 3. Hierarchical control**
- 4. Robustness**

Design concept



- 1. Biological inspiration vs direct copying**
- 2. Taming of complexity**

Design concept



**1. *Biological inspiration vs
direct copying***

2. Taming of complexity

Biomimicry



**Copy
Nature**

Evolution - “just good enough”

Technologies



Human

Large

Flat, rt angles

Stiff

Rolling devices

*Few actuators
& sensors*

Natural

Small

Curved

Bends, twists

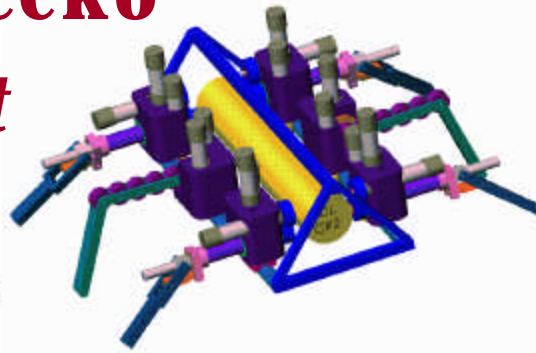
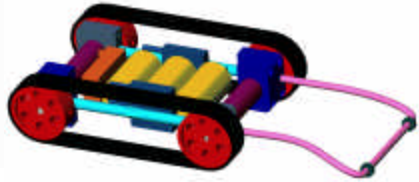
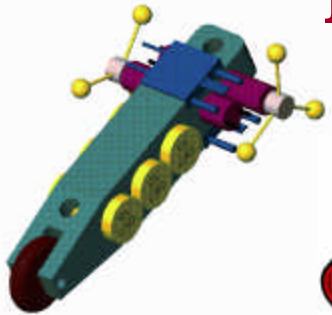
Legs

*Many actuators
& sensors*

Inspiration



Mecho-Gecko *iRobot*



**Use Concepts
And Analogies
When
Advantageous**

**Nature provides useful hints
at what is possible.
As human technology takes
on more of the characteristics
of nature,
nature becomes a more useful
teacher.**

Design concept



- 1. Biological inspiration vs direct copying**
- 2. *Taming of complexity***

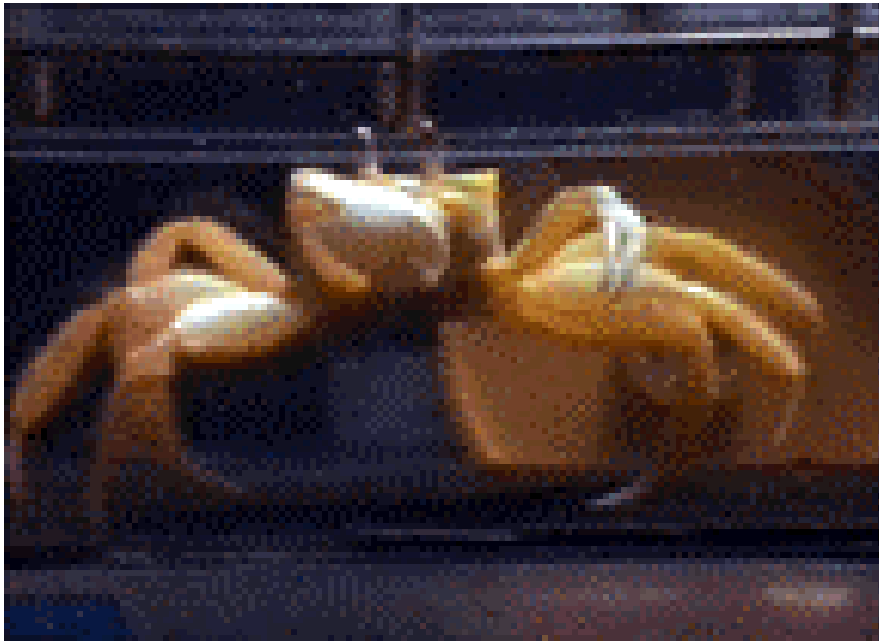
Reduce Complexity



Analyze motion of animal. Search for joint synergies. Reduce degrees of freedom from 9 to 2 per leg.

Ghost Crab - UC Berkeley

Ariel First Legged Amphibious Robot - IS Robotics



QuickTime™ and a
decompressor
are needed to see this picture.

Energy management

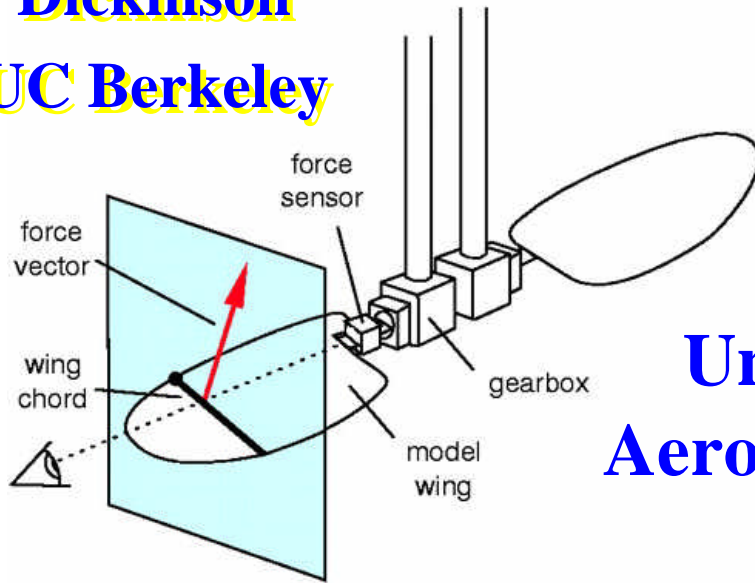


- 1. Energy exchange and storage**
- 2. Interaction with environment**
- 3. Performance of actuators**
 - energy density**
 - broad role**

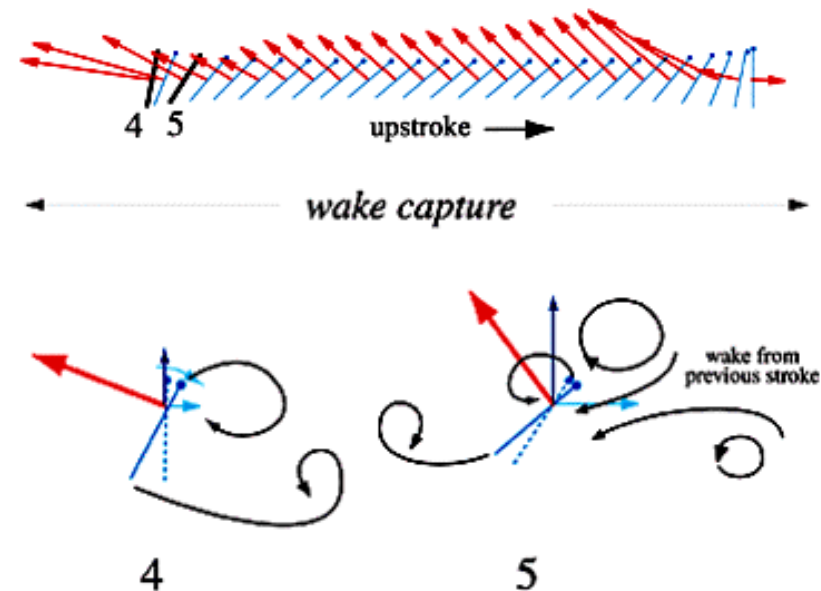
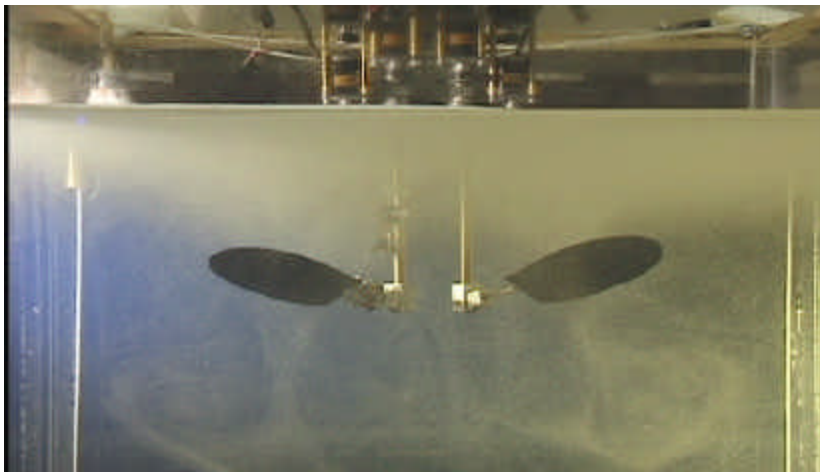
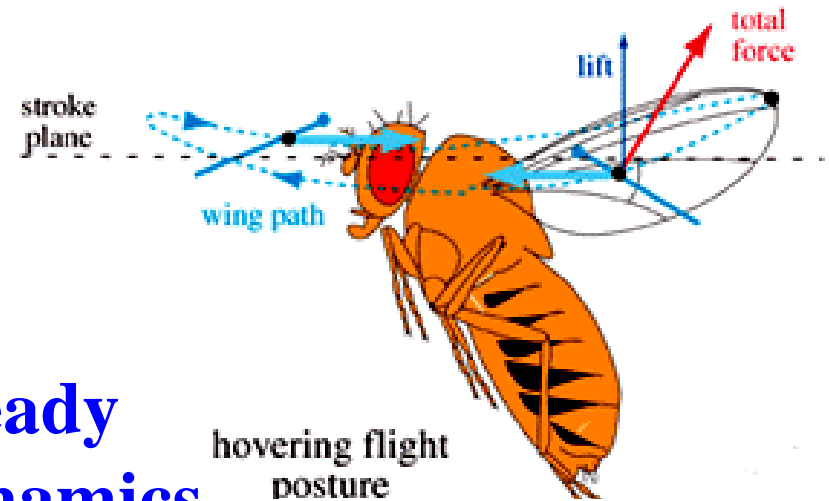
Robofly & Wake Recapture



Dickinson
UC Berkeley

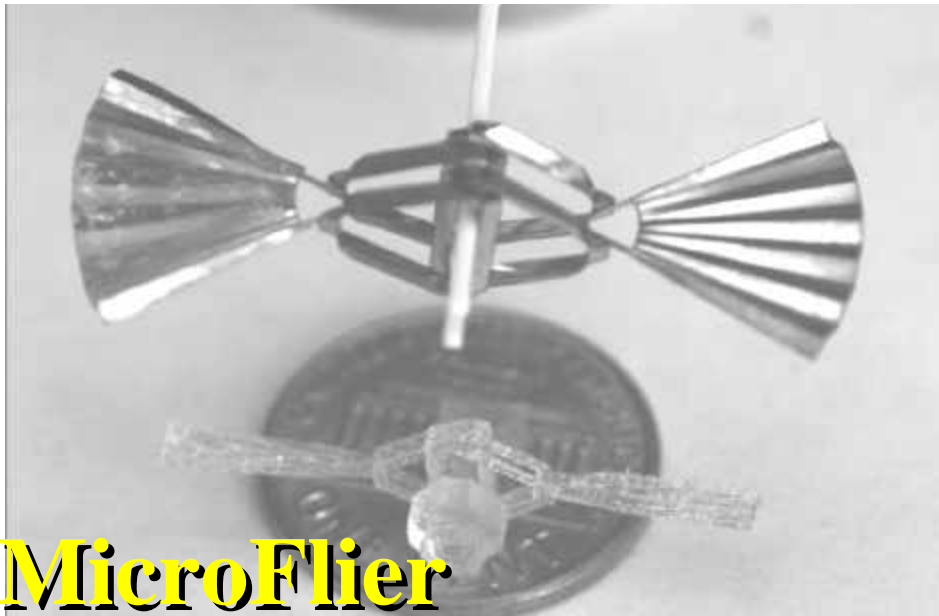


Unsteady Aerodynamics



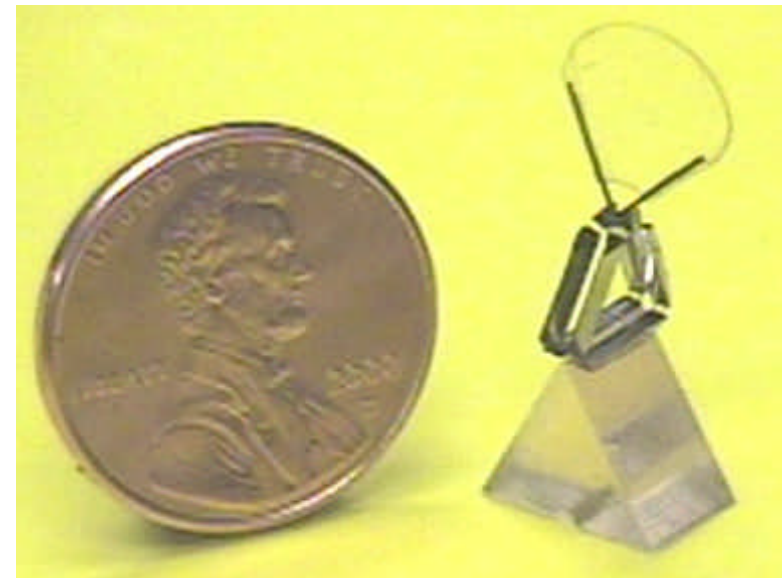


Tuned Thorax & Wing Design



MicroFlier

MFI component	size	total mass
4-bar frames (2 per wing)	links 5,5,4, 0.7 mm	20 mg
1 mm box beam base frame (mm)	$10 \times 4 \times 1$ mm	8 mg
piezo actuator (2 per frame)	$0.25 \times 5 \times 0.2$ mm	15 mg
wings (polyester)	$5 \times 10 \times .01$ mm	3 mg
total structure		43 mg



Fearing UC Berkeley

Hierarchical control



- 1. Identify target of control**
- 2. Passive dynamics**
 - smart or tuned mechanical system**
- 3. Sensory fusion and integration**

Flexible Leg



5-Bar Linkage



**Deflected Specimen of
Multi-Material**

Arthro-Leg Principles

**Stanford University
Cutkosky and Cham**

Shape Deposition

Manufacturing

**allows Heterogeneous
Materials**

Dynamic Hexapod

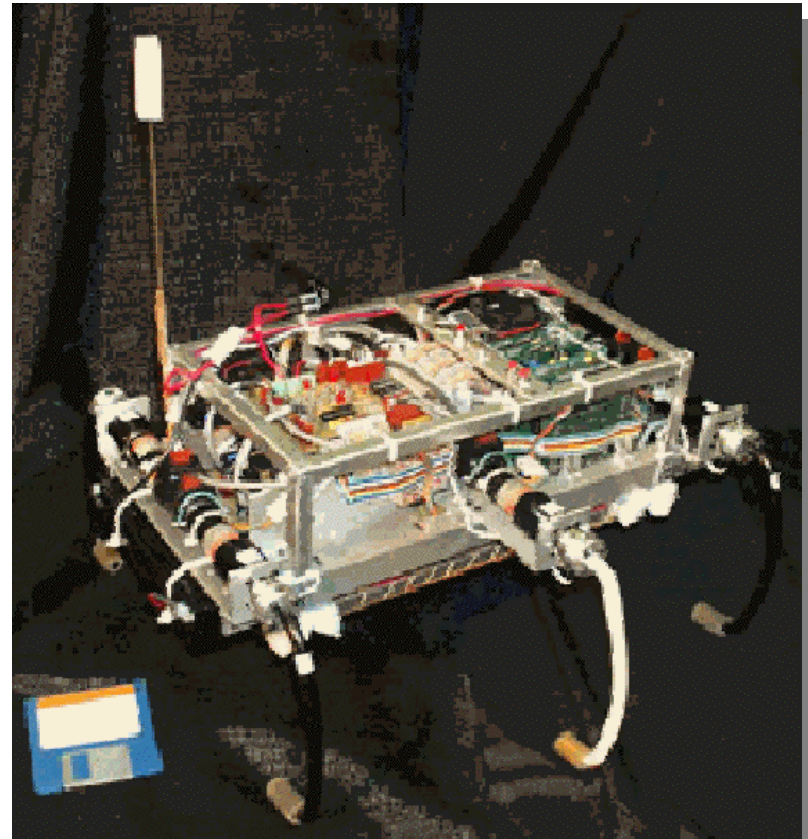


Rhex

**Biologically
Inspired
Bouncing
Robot**

**Buehler
&
Koditschek**

**McGill University &
University of Michigan**



Robustness



- 1. Redundancy**
- 2. Modularity**
- 3. Learning and adaptation**

Defense Relevant Implications



- 1. Search and rescue (e.g. after a terrorist bombing or in a fire)**
- 2. Detection, sampling and removal of biohazards, mines and other devices**
- 3. Reconnaissance and surveillance**
- 4. Human augmentation (extend sensory and motor capability)**

BioMotion Vision



- 1. Control and program motion**
- 2. Move in any environment**
- 3. Manipulate any object**

Building the Community



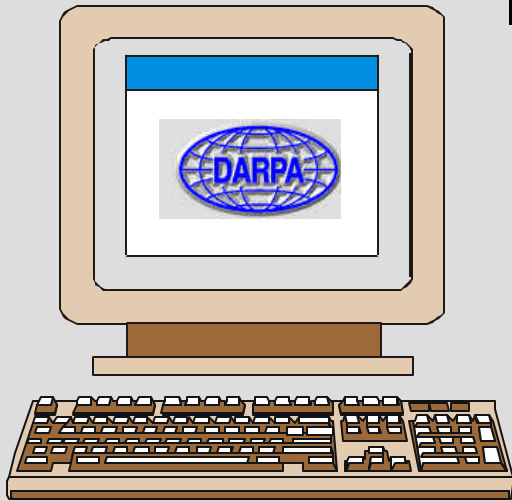
- 1. Identifying the community**
- 2. Mutualistic Teaming**
- 3. Integrative Training**
- 4. Building strong scientific foundation to hasten revolutionary deliverables**

Vision - Next Revolution



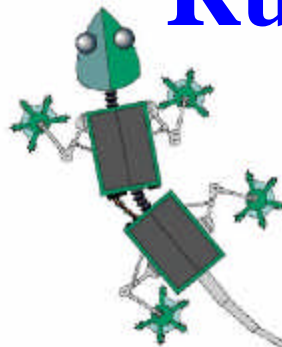
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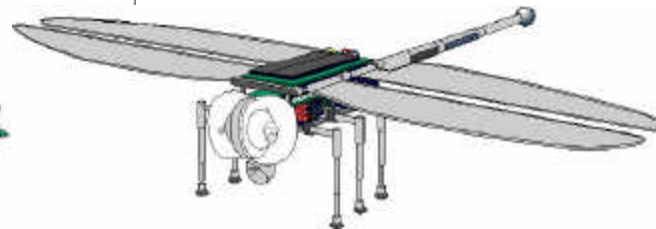


Programmable Work
Legs and Hands

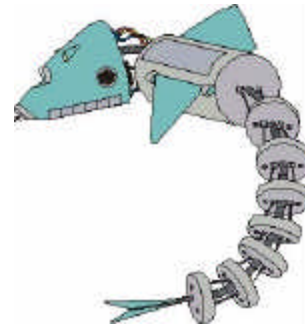
Run



Fly



Swim



**Worldwide
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Transfer**

Eyes and Ears

Koditschek - UM